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BASE BLEED GRAIN GENERATOR UPGRADING FOR USE IN 155-52 CALIBER - DESIGN AND CHARATERIZATION

Yves FUSEAU - Jean-Louis PAULIN
SNPE Explosives & Propellant - 12, quai Henri IV 75181 PARIS Cedex 04 - FRANCE

ABSTRACT

In order to increase artillery shells range when fired in a given gun system the best solution remains those which optimises both performance and accuracy. The reduction of aerodynamic drag leads to win up to 30 % in range without guidage which is necessary when using additional propulsion. This is base bleed technology.

This technology has been used since 1986 especially for 105 and 155 mm artillery shells. Most of the grains are realised with AP as oxidizing charge and HTPB as binder using cast composite technology.

The operating conditions in the barrel like strong pressure gradients, high temperature of gases and strong axial and rotational accelerations are severe for composite propellant, so range accuracy is often lower if in-flight mass flow function changes from one generator to one other.

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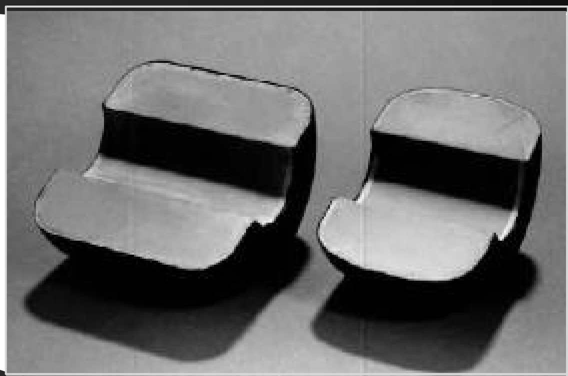


SNPE team has carried on PRB Company previous efforts with a new composition: TPE binder and new process: pressed technology more fitted with small grains mass production.

Furthermore this technology gives real advantages to adapt the shape of the grain to the inner design of the metal base and a strong cohesive bonding propellant insulator.

Experience over 10 years when firing in very cold conditions for 155 mm 39 and 52 cal shows that it is necessary to upgrade the behaviour of the base bleed grains in these conditions.

A new definition of a propellant composition having a lower glass transition point has been achieved. Then, the definition of a new grain has been realised with a new design in two half grains suitable with the optimised drawing of the metal base for higher mechanical resistance.

Mechanical properties of base bleed grain are enhanced in cold conditions. This new definition is fully compatible with new 155-52 calibre projectiles

TPE BINDER AND PRESSED TECHNOLOGY

This technology is a solvent way using a thermoplastic binder instead of HTPB with ammonium perchlorate cast process and composition.

The first step of the process is to mix the different components with a solvent. After extrusion of small granules the solvent is removed and the granules are hot pressed in a mould with the insulator.

The excess part of inhibitor is then removed and the grain is RX and dimensionally controlled.

This technology is very suitable for the base bleed applications because:

- process enables : - high production rate and reliable manufacturing - complex shape design - dimensional control from tooling - no bubbles or cracks - no sedimentation - no cure cycle - only press tooling - low cost.
- propellant composition grants : - good mechanical properties - strong cohesive bonding between the propellant and the insulator which use the same binder - low sensitivity to relative humidity - easy adjustment of burning rate with catalyst - easy demilitarisation - low cost binder.

FIRING TEST RESULTS

Firing tests show… for the different associations: shell + propelling charge + base bleed grain

for different temperature of the projectile

…….different types of functioning in term of performance (dispersion and range).

The dispersion in the range...

is the consequence of the behaviour of the system : projectile, base bleed, re-ignitor and propelling charge,

….. mainly appears in the results as follow:

- In cold conditions (- 40 °C) with TPE1 formulation experienced in 155 mm 39 and 52 caliber
- In warm conditions (+63 °C) with HTPB formulation experienced in 105 and 155 mm 52 caliber.

CARACTERISATION OF THE DIFFERENT FORMULATIONS

SAFETY

To be able to manufacture and use the base bleed grains the pyrotechnic characteristics of the different compositions have been tested.

Although the ammonium perchlorate ratio and the binder are different in the 2 compositions the safety data are very close together.

	TPE family	PBHT family
Self ignition temperature (°C)	262	278
Shock Impact sensitivity (m)	≥ 4	≥ 4
Friction sensitivity (N)	288	203
Burning rate at atmospheric pressure (mm/s)	≤ 1.6	≤ 1.6
CGT (cards)	≤ 1	≤ 1
Electrostatic sensitivity	no	no

CARACTERISATION OF THE DIFFERENT FORMULATIONS

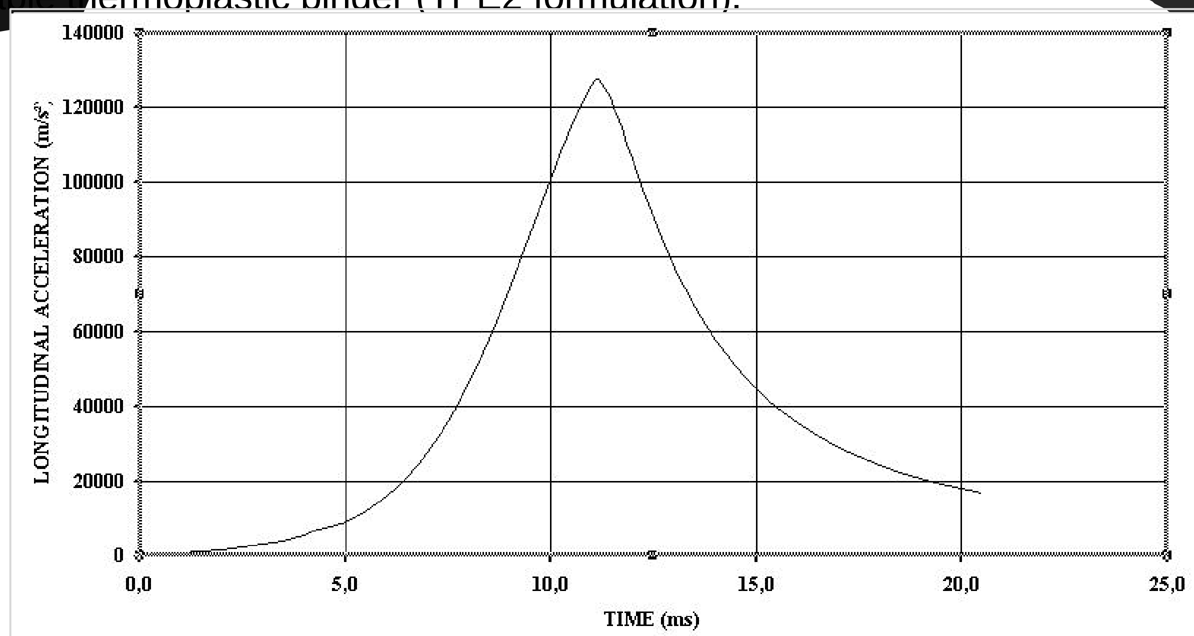
MECHANICAL PROPERTIES

Due to high longitudinal and rotating acceleration strains are developed in the core of the grain. So the propellant must keep at every temperature and in every calibre a high flexibility.

Requirements for new systems are extended towards - lower temperatures: - 40 instead of - 30 °C - higher temperatures: +60 or 63 instead of + 52 °C - higher muzzle velocity: 52calibres

➡ So the mechanical properties of the TPE1 formulation have been upgraded for the cold temperatures with a more suitable thermoplastic binder (TPE2 formulation).

EXEMPLE OF THE LONGITUDINAL ACCELERATION IN A 155 39 CALIBRE BARREL



CARACTERISATION OF THE DIFFERENT FORMULATIONS

Main characteristics measured using a tensile speed of 10 to 20 mm/min,

measured glass transition point,

are given for the different kind of compositions

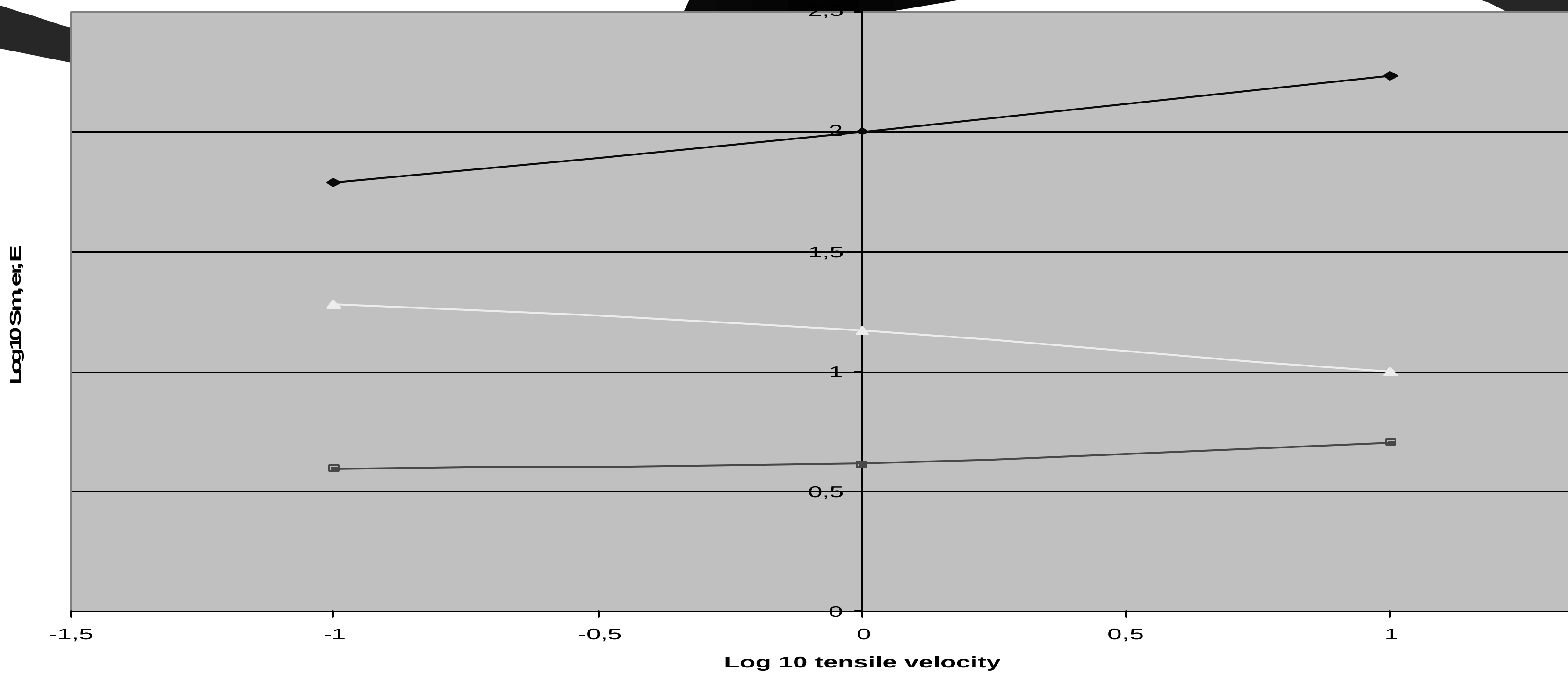
		TPE1			TPE2			PBHT		
		-40°C	+20°C	+60°C	-40°C	+20°C	+75°C	-40°C	+20°C	+75°C
Mechanical properties	Sm (MPa)	≥ 5.0	≥ 1.8	≥ 1.8	≥ 6.5	≥ 4	≥ 2.7	≥ 4	≥ 1.0	≥ 1.2
	em (%)	≥ 40	≥ 40	≥ 25	≥ 5	≥ 5	≥ 10	≥ 5	≥ 30	≥ 40
	E (MPa)	≥ 250	≥ 18		≥ 500	≥ 240	≥ 50	≥ 70	≥ 5.5	≥ 5.5
Glass transition point (°C)		-60			-93			-63		

Temperature has a strong effect on properties,

tensile velocity too as we can see below

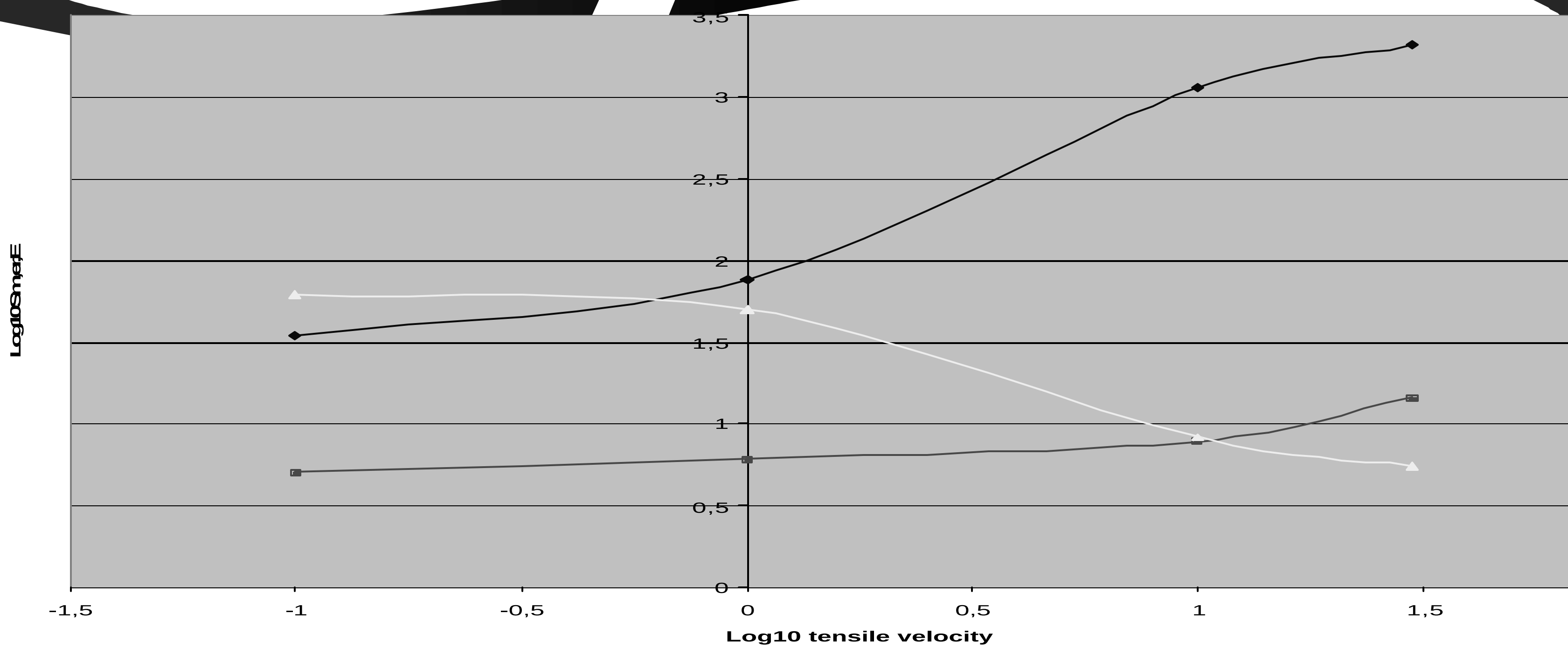
MECHANICAL PROPERTIES AT -40°C AT DIFFERENT TENSILE VELOCITIES FOR HTPB

Tensile velocity (mm/min)	ε· (1/s)	er (%)	Sm (Mpa)	E (Mpa)
180	0.1	19	4	62
1800	1	15	4.2	102
18000	10	10	5.1	170



MECHANICAL PROPERTIES AT -40°C AT DIFFERENT TENSILE VELOCITIES FOR TPE 1

Tensile velocity (mm/min)	$\dot{\varepsilon}$ (1/s)	er (%)	Sm (Mpa)	E (Mpa)
180	0.1	62	5.1	35.2
1800	1	50.5	6.2	77.5
18000	10	8.3	7.9	1143
60000	30	5.5	14.6	2080



MECHANICAL PROPERTIES AT -40°C AT DIFFERENT TENSILE VELOCITIES

These curves are used to compute the mechanical behaviour of the grain and the safety margins during the internal ballistic phase at –40°C.

Another way to measure the mechanical properties is to use a visco analyser.

With only 1 test we can measure on a sample of propellant the mechanical properties between –80°C and + 80°C with different frequencies (different strains) applied on the sample and also deduce the glass transition point.

GLASS TRANSITION POINT (°C)

Results obtained with this method are very closed to those obtained with tensile tests.

The glass transition point is also closed to those obtained by ATD method

	TPE1	TPE2	HTPB
Visco analyser	- 65	- 81	- 59
ATD	- 63	- 93	- 65

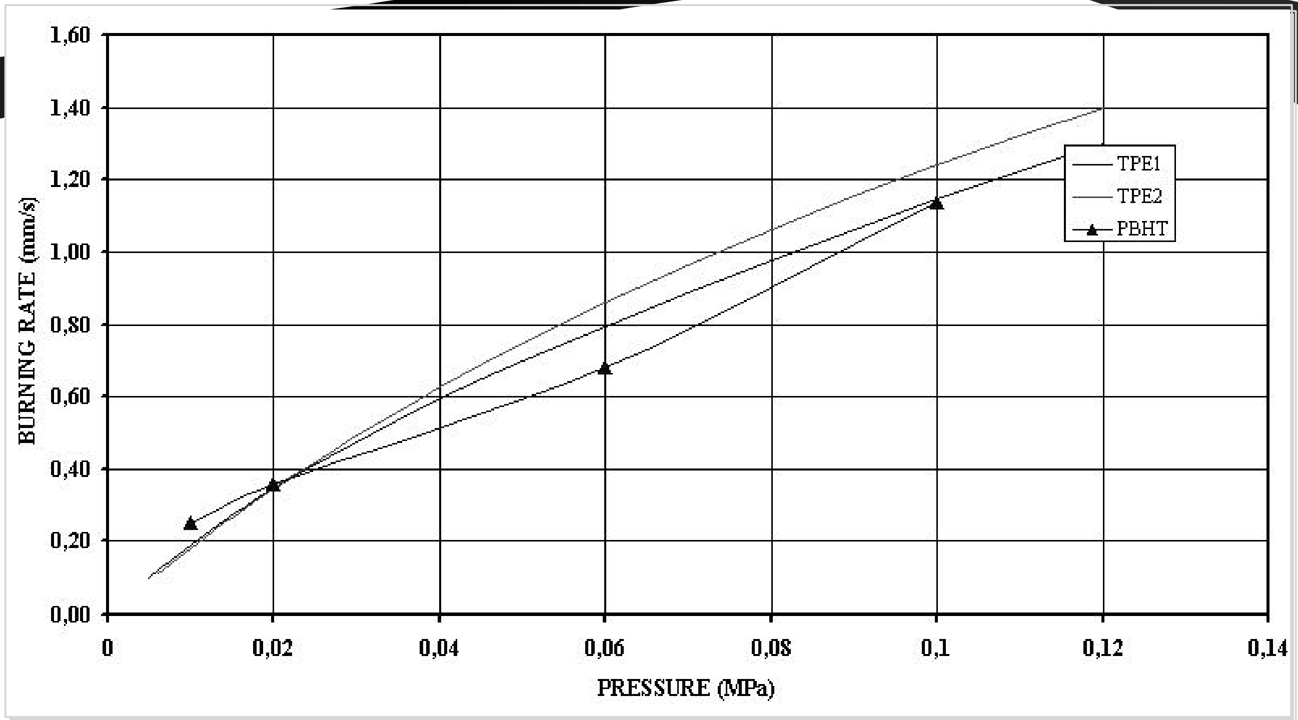
BURNING RATE

The burning rate measurements have been realised either using a strand burner method (for PBHT) or an ultra sonic method (for TPE).

Using an ultra sonic transducer we obtain a continuous measurement of the burning rate. The evolution of the burning rate versus pressure between 0.01 and 0.1 MPa is obtained in only one test.

The burning rate is optimised to take in account the size of the grain and the drag law of the shell.

BURNING RATE VERSUS PRESSURE



THERMODYNAMICAL PROPERTIES

Composite propellant are either with polymeric binder HTPB or thermoplastic binder TPE loaded with an oxidizer AP. Some other additives are added to obtain final composition.

Thermodynamic data are computed with BAGHEERA code

	TPE	HTPB
Binder (%)	22	18
Oxydizer (%)	75	80
Bonding agent (%)	1.5	0.1
Curing agent (%)	-	1.4
Antioxydant (%)	0.25	0.4
Catalyst (%)	1.25	0.1
Flame temperature (K)	1693	2370
Density	1.55	1.59
Isentropic coefficient	1.2	1.2

EXTERNAL BALLISTIC

A small 2D computer code is used to compare the range that can be achieved by a shell with different base bleed grains definition.

The code based on the Swedish model of Gunners and al. computes the drag obtained at the base when the base bleed burns and the range achieved.

Taking in account the different results obtained with different hypothesis : geometry of the base bleed grain, burning rate, muzzle velocity, elevation ... solutions can be selected to optimise the range.

The code does not take in account the Coriolis effect and the effect of the rotation of the shell.

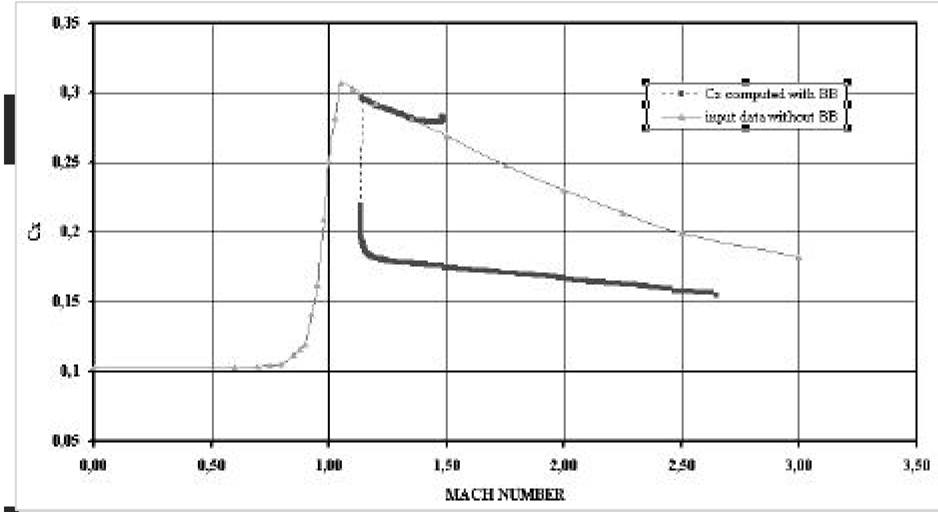
The input data are the following :

- Concerning the gun : elevation, muzzle velocity
- Concerning the shell : mass, drag law without base bleed, dimensions
- Concerning the propellant : thermodynamic characteristics (isentropic coefficient, heat of combustion, burning rate law versus pressure,
- Concerning the grain : burning area versus burning thickness law.

The output data are :

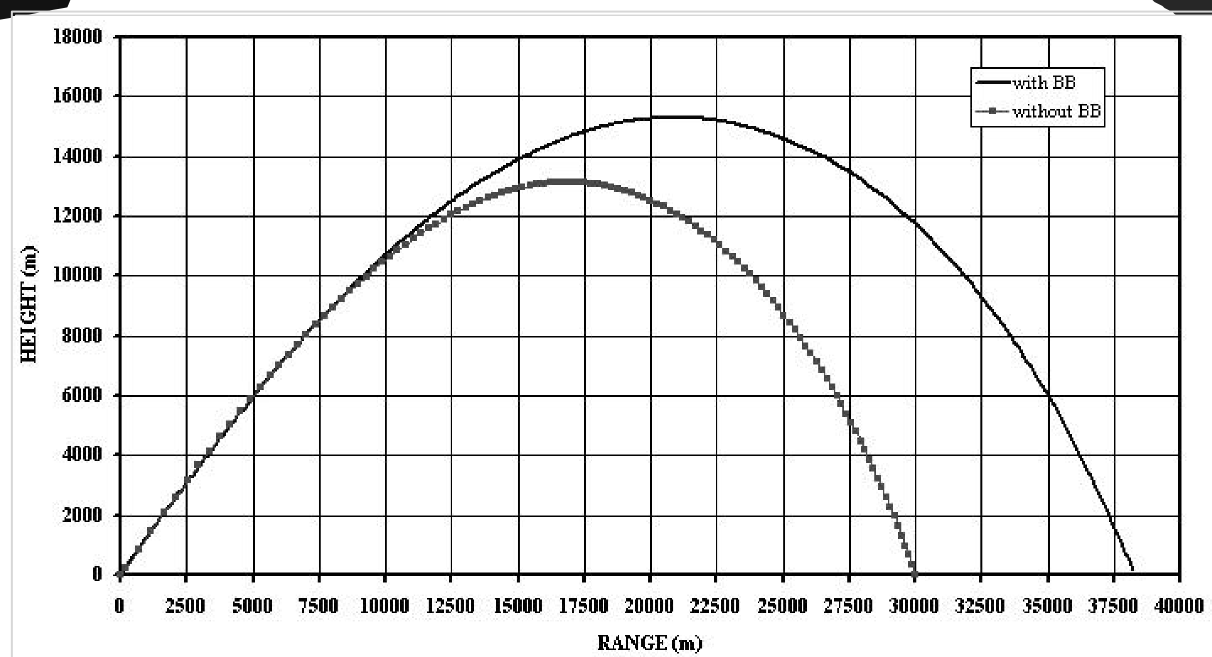
- Concerning the shell : range, trajectory, base drag, mach number,
- Concerning the base bleed : burning time, mass flow rate.

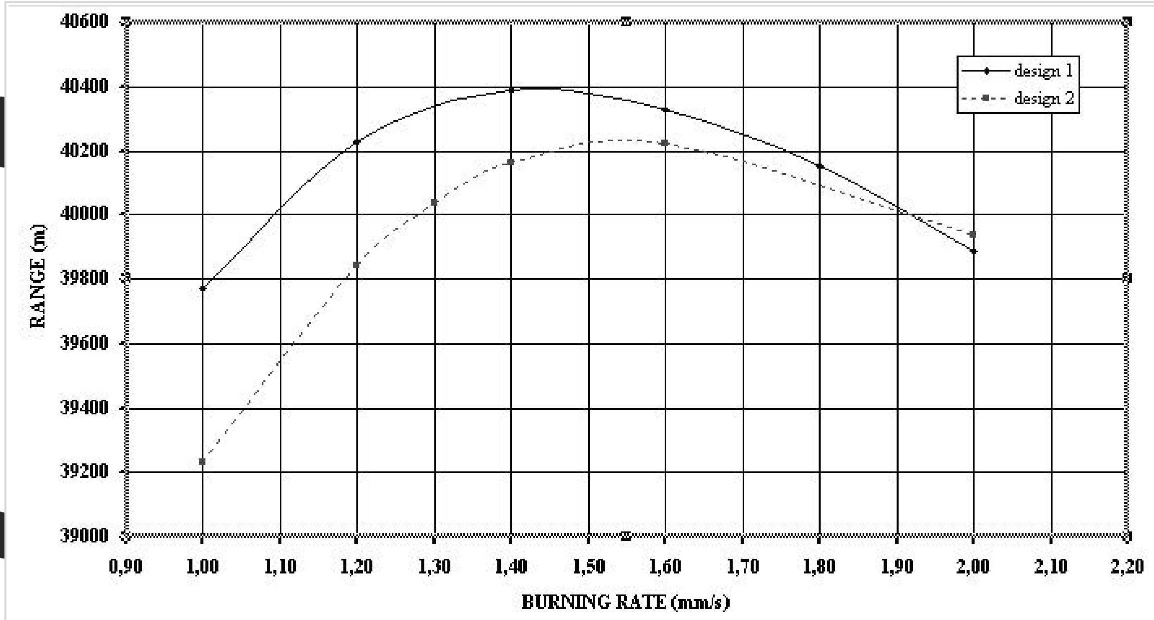
EXEMPLE OF CALCULATION IN 155 52 cal



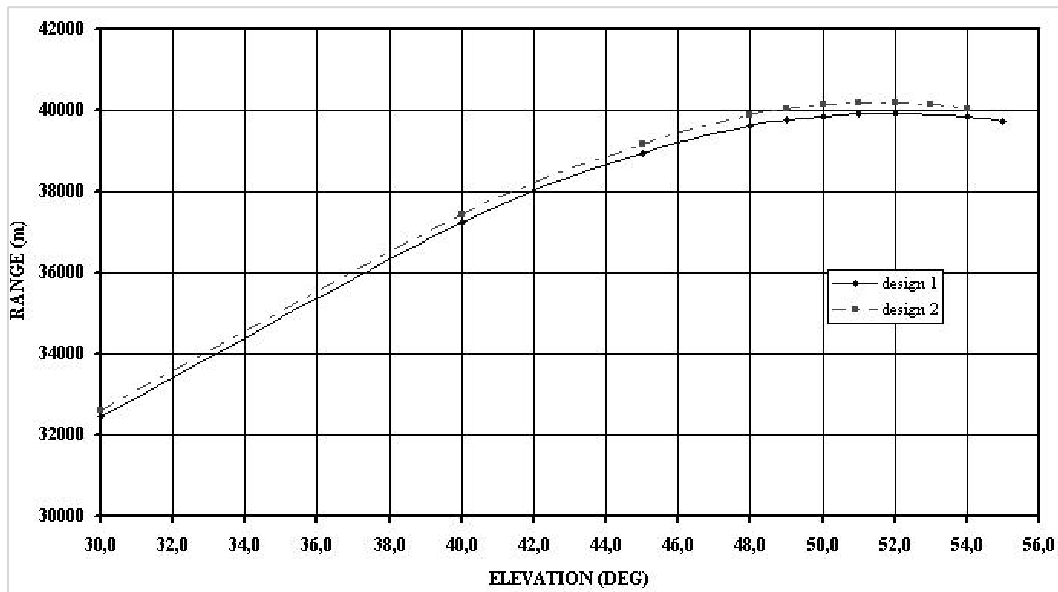
Cx versus Mach number with and without base bleed

Computed trajectory



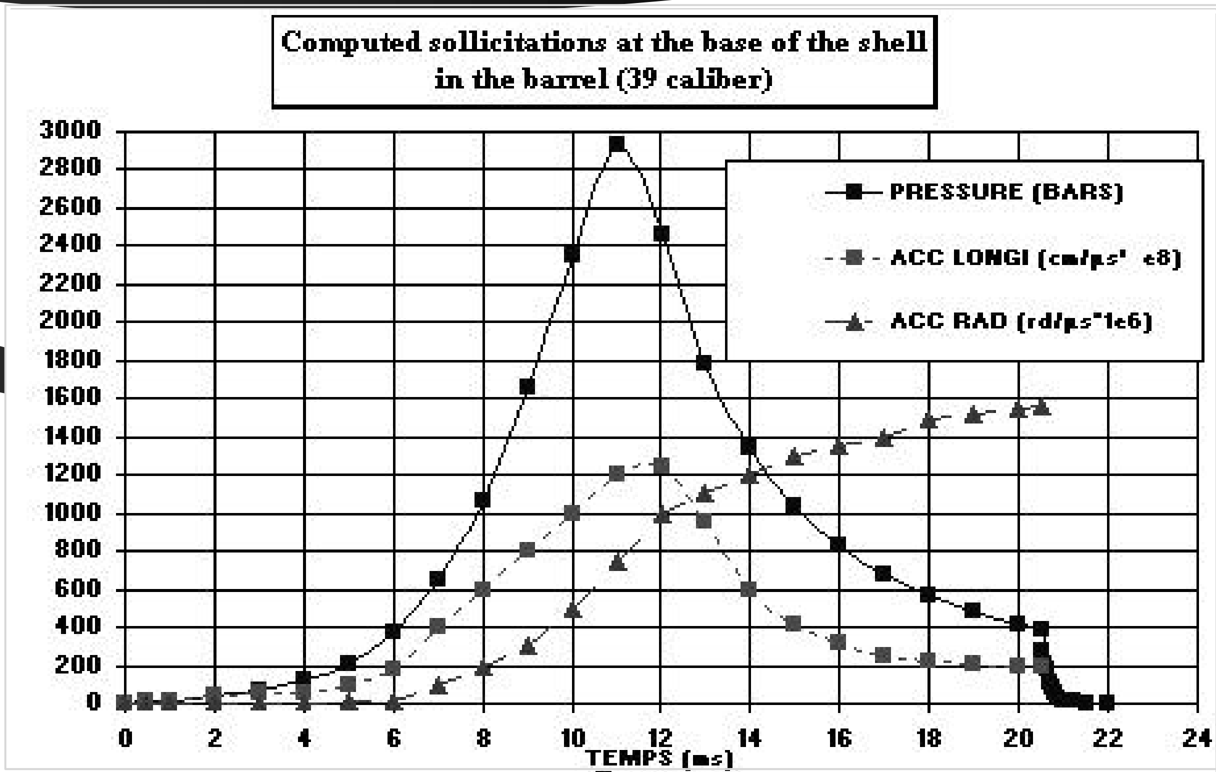


BASE BLEED DESIGN
Effect of burning rate on range for two grains geometry: S/So design (1) and (2)



For each optimum burning rate and the two geometries (1) (2) max range are different and required differents elevations between 50 and 54 degrees

MECHANICAL WITHSTANDING CALCULATION OF THE GRAIN IN THE BARREL



A mechanical code DYNA which takes in account the shape of the grain, the mechanical properties of the propellant measured under high tensile speeds (up to 1 m/s) as described above in the range of required temperatures (-40 + 60 °C) allows to compare the computed strength in the mass of the propellant during the time of the solicitation to the mechanical properties.

From this comparison we can obtain “a safety coefficient”. If the computed strength is lower than the measured mechanical properties we can deduct that the grain will not break and the geometrical deformation will be acceptable.

MECHANICAL WITHSTANDING CALCULATION OF THE GRAIN IN THE BARREL

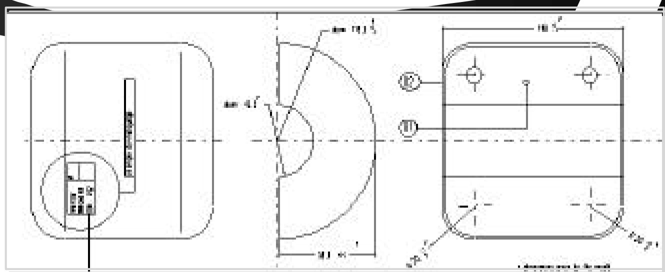
1	Temperature (°C)	- 40
2 (measured)	Deformation (s^{-1})	2.05
3 (measured)	E (Mpa)	257
4 (measured)	Strain (Mpa)	7.59
5 (computed)	Stress elastic	2.96 10^{-2}
6 (computed)	Stress plastic	1.55 10^{-2}
7 = (5) + (6)	Stress (total)	4.51 10^{-2}
8 (read on the experimental curve taking in account the maximum stress)	Measured Failure stress	20.6 10^{-2}

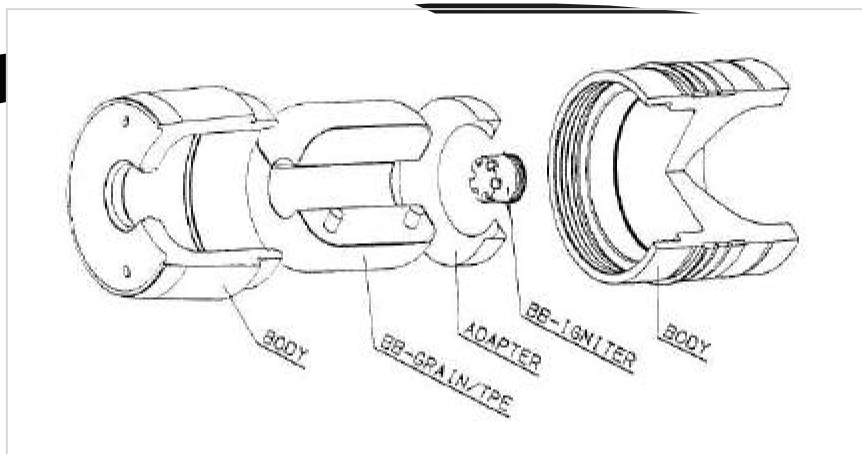
As it can be seen the maximum computed solicitation seen by the propellant is 4.51 10^{2} (line 7) is quite 4 times lower than the measured value (line 8).

So we can deduct that the propellant grain in these conditions will not break in the barrel.

DEFINITION OF A 52 CALIBER GRAIN

The result of the methodology applied to define a 52 caliber gun can lead for a given shell the definition hereafter :





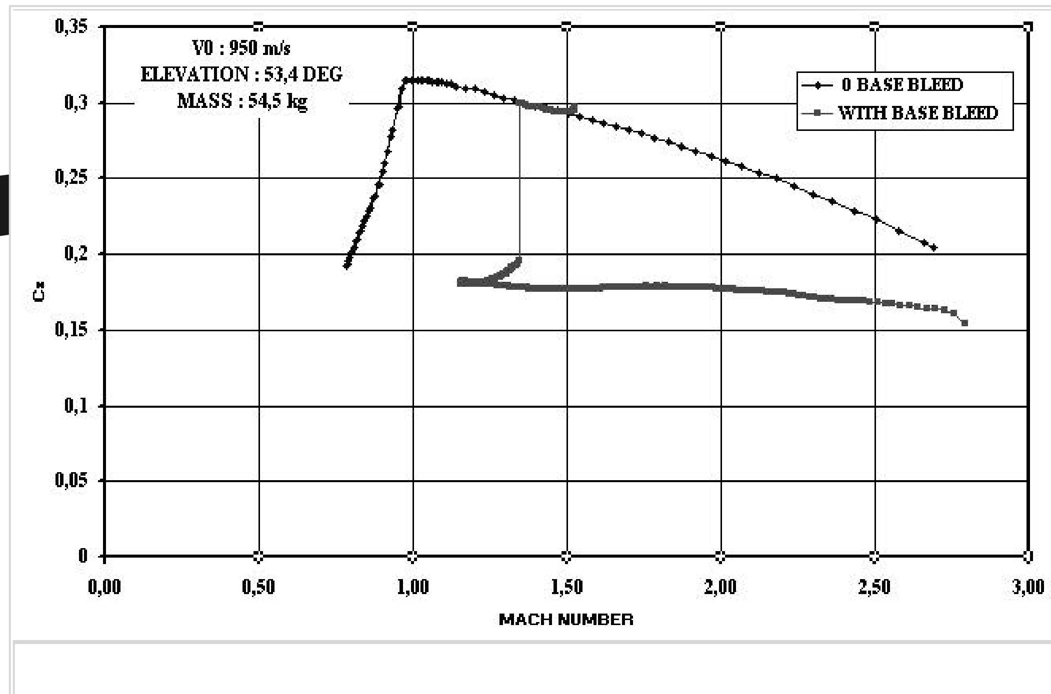
The burning rate of the propellant (20 °C) chosen at atmospheric pressure is 1.3 mm/s.

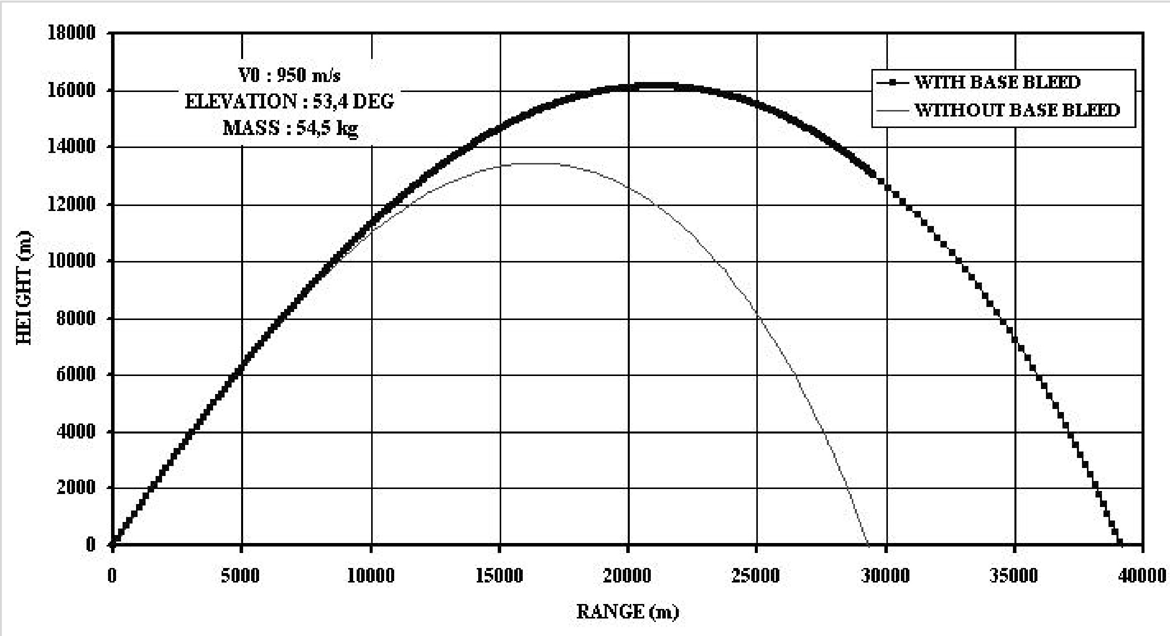
The glass transition point is under – 90 °C and the mechanical properties are those of TPE2 table.

DRAG COEFFICIENT VERSUS MACH NUMBER

For this definition, the base drag reduction for the projectile (weight : 45.5 kg) is shown below

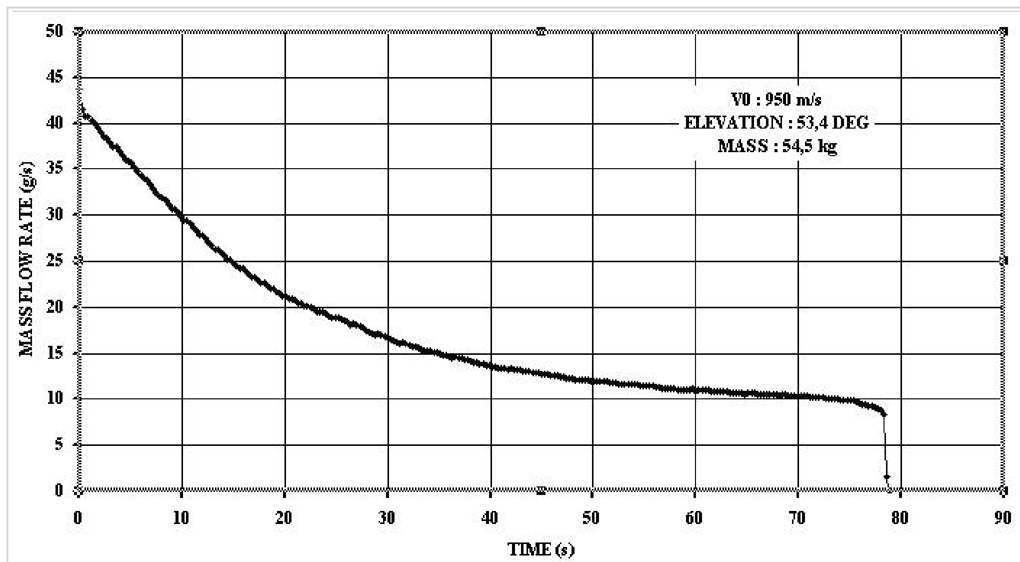
DRAG COEFFICIENT VERSUS MACH NUMBER





EFFECT ON TRAJECTORY
projectile weight : 45.5 kg
muzzle velocity: 950 m/s

IN-FLIGHT
BASE BLEED MASS FLOW RATE



GLOBAL STEP FOR BASE BLEED GRAIN AND KIT DESIGN

Scope	Solicitation			Capacity	
	Element environment	Definition	Modelisation	Definition	Tests and measurements
Ignition	bb grain/propelling charge	grain ignition by gun propellant charge gases	convective ignition and conductive	ignitability of bb grain propellant	convective ignition test device - flame spreading test
	bb grain/bb igniter	grain ignition by igniter gases and particles	convective and conductive ignition	ignitability of bb grain propellant	bb igniter flux emission
	bb grain/shear disc	cavity pressurisation	charge IB calculation	ignitability of the bb grain under pressure	grain ignition test device with shear disc
	bb grain/temperature	bb grain temperature condition		d° under temperature	d° at –40°C
Combustion and functioning	bb grain/IB motor	running calculation	BALEX code	range	gun firing test
	bb grain/ Flight ambient pressure and altitude	aerodynamic calculation	d° + PATRIC code	max flow function vb = f (P)	vb = f (P) strand burner deflagration limit pressure vb = f (P) high altitude tank simulation
	bb grain/artillery muzzle velocity and acceleration	burning under stress		propellant burning law under stress	burning rate on spin mock up test
	bb grain/temperature	bb grain initial temperature condition		d° under temperature	d° at – 40°C
Mechanical behaviour	bb grain/propelling charge	stress calculation during IB phase from gases and gun propellant grains	MOBIDIC code, projectile base intergranular stress and bb cavity calculation	mechanical withstanding under stress	shot gun test viscoanalyser test mechanical control curves
	bb grain/artillery muzzle velocity and acceleration	stress calculation during Ext Ballistic versus velocity and acceleration	ABAQUS code for gain deformation	d°	d°
	bb grain/ temperature	d° + bb grain initial temperature condition	grain –40°C ; + 63 °C	d° versus temperature	d° at –40°C and+ 63°C
	bb grain/temperature	d° + propelling charge initial temperature condition	charge + 20°C ; + 63°C		

CONCLUSIONS

The pressed base bleed propellant technology represents a significant advance in the production of small propellant charges and was chosen for new developments

Experience over 10 years have shown small margin and some failures by using either cast and HTPB or pressed and TPE1 grains

We have chosen to improve the TPE binder and pressed technology in order to reach new requirements in 155 52 calibre: extended range of temperature and projectile velocity

The new TPE2 formulation was selected and show for each scope of the global step methodology established for the design : ignition, combustion and functioning, mechanical behavior capacity > solicitation.

New base bleed grains were designed for different projectiles and are either in development either in production with TPE2 binder and AP charge. After the first grain KHEOPS type classified in 155 mm 39 and 45 calibre with ERFB, they are called AMON, SEHTI, TOUTMOSIS and are able to reach the required solicitation levels in 155 52 calibre guns. Firing tests are still in progress.